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Determination of the top-quark pole mass and strong coupling constant from the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV

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ABSTRACT

The inclusive cross section for top-quark pair production measured by the CMS experiment in proton–proton collisions at a center-of-mass energy of 7 TeV is compared to the QCD prediction at next-to-next-to-leading order with various parton distribution functions to determine the top-quark pole mass, m_t^{pole}, or the strong coupling constant, α_S. With the parton distribution function set NNPDF2.3, a pole mass of $176.7^{+3.8}_{-3.4}$ GeV is obtained when constraining α_S at the scale of the Z boson mass, m_Z, to the current world average. Alternatively, by constraining m_t^{pole} to the latest average from direct mass measurements, a value of $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$ is extracted. This is the first determination of α_S using events from top-quark production.

1. Introduction

The Large Hadron Collider (LHC) has provided a wealth of proton–proton collisions, which has enabled the Compact Muon Solenoid (CMS) experiment [1] to measure cross sections for the production of top-quark pairs ($t\bar{t}$) with high precision employing a variety of approaches [2–10]. Comparing the presently available results, obtained at a center-of-mass energy, $\sqrt{s}$, of 7 TeV, to theoretical predictions allows for stringent tests of the underlying models and for constraints on fundamental parameters. Top-quark pair production can be described in the framework of quantum chromodynamics (QCD) and calculations for the inclusive $t\bar{t}$ cross section, $\sigma_{t\bar{t}}$, have recently become available to complete next-to-next-to-leading order (NNLO) in perturbation theory [11]. Crucial inputs to these calculations are: the top-quark mass, m_t; the strong coupling constant, α_S; and the gluon distribution in the proton, since $t\bar{t}$ production at LHC energies is expected to occur predominantly via gluon–gluon fusion.

The top-quark mass is one of the fundamental parameters of the standard model (SM) of particle physics. Its value significantly affects predictions for many observables either directly or via radiative corrections. As a consequence, the measured m_t is one of the key inputs to electroweak precision fits, which enable comparisons between experimental results and predictions within and beyond the SM. Furthermore, together with the Higgs-boson mass and α_S, m_t has direct implications on the stability of the electroweak vacuum [12,13]. The most precise result for m_t, obtained by combining direct measurements performed at the Tevatron, is 173.18 ± 0.94 GeV [14]. Similar measurements performed by the CMS Collaboration [2,15–17] are in agreement with the Tevatron result and of comparable precision. However, except for a few cases [17], these direct measurements rely on the relation between m_t and the respective experimental observable, e.g., a reconstructed invariant mass, as expected from simulated events. In QCD beyond leading order, m_t depends on the renormalization scheme [18,19]. The available Monte Carlo generators contain matrix elements at leading order or next-to-leading order (NLO), while

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higher orders are simulated by applying parton showering. Studies suggest that m_{t} as implemented in Monte Carlo generators corresponds approximately to the pole ("on-shell") mass, $m_{\mathrm{t}}^{\mathrm{pole}}$, but that the value of the true pole mass could be of the order of 1 GeV higher compared to m_{t} in the current event generators [20]. In addition to direct m_{t} measurements, the mass dependence of the QCD prediction for $\sigma_{\mathrm{t\bar{t}}}$ can be used to determine m_{t} by comparing the measured to the predicted cross section [13,19,21–24]. Although the sensitivity of $\sigma_{\mathrm{t\bar{t}}}$ to m_{t} might not be strong enough to make this approach competitive in precision, it yields results affected by different sources of systematic uncertainties compared to the direct m_{t} measurements and allows for extractions of m_{t} in theoretically well-defined mass schemes. It has been advocated to directly extract the $\overline{\mathrm{MS}}$ mass of the top quark using the $\sigma_{\mathrm{t\bar{t}}}$ prediction in that scheme [21]. The relation between pole and $\overline{\mathrm{MS}}$ mass is known to three-loop level in QCD but might receive large electroweak corrections [25]. In principle, the difference between the results obtained when extracting m_{t} in the pole and converting it to the $\overline{\mathrm{MS}}$ scheme or extracting the $\overline{\mathrm{MS}}$ mass directly should be small in view of the precision that the extraction of m_{t} from the inclusive $\sigma_{\mathrm{t\bar{t}}}$ at a hadron collider provides. Therefore, only the pole mass scheme is employed in this Letter.

With the exception of the quark masses, α_S is the only free parameter of the QCD Lagrangian. While the renormalization group equation predicts the energy dependence of the strong coupling, i.e., gives a functional form for $\alpha_S(Q)$, where Q is the energy scale of the process, actual values of α_S can only be obtained based on experimental data. By convention and to facilitate comparisons, α_S values measured at different energy scales are typically evolved to $Q = m_{\mathrm{Z}}$, the mass of the Z boson. The current world average for $\alpha_S(m_{\mathrm{Z}})$ is 0.1184 ± 0.0007 [26]. In spite of this relatively precise result, the uncertainty on α_S still contributes significantly to many QCD predictions, including expected cross sections for top-quark pairs or Higgs bosons. Furthermore, thus far very few measurements allow α_S to be tested at high Q and the precision on the average for $\alpha_S(m_{\mathrm{Z}})$ is driven by low-Q measurements. Energies up to 209 GeV were probed with hadronic final states in electron–positron collisions at LEP using NNLO predictions [27–30]. Jet measurements at the Tevatron and the LHC have recently extended the range up to 400 GeV [31], 600 GeV [32], and 1.4 TeV [33]. However, most predictions for jet production in hadron collisions are only available up to NLO QCD. Even when these predictions are available at approximate NNLO, as used in [34], they suffer from significant uncertainties related to the choice and variation of the renormalization and factorization scales, μ_R and μ_F, as well as from uncertainties related to non-perturbative corrections.

In cross section calculations, α_s appears not only in the expression for the parton–parton interaction but also in the QCD evolution of the parton distribution functions (PDFs). Varying the value of $\alpha_S(m_{\mathrm{Z}})$ in the $\sigma_{\mathrm{t\bar{t}}}$ calculation therefore requires a consistent modification of the PDFs. Moreover, a strong correlation between α_S and the gluon PDF at large partonic momentum fractions is expected to significantly enhance the sensitivity of $\sigma_{\mathrm{t\bar{t}}}$ to α_S [35].

In this Letter, the predicted $\sigma_{\mathrm{t\bar{t}}}$ is compared to the most precise single measurement to date [6], and values of $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_{\mathrm{Z}})$ are determined. This extraction is performed under the assumption that the measured $\sigma_{\mathrm{t\bar{t}}}$ is not affected by non-SM physics. The interplay of the values of $m_{\mathrm{t}}^{\mathrm{pole}}$, α_s and the proton PDFs in the prediction of $\sigma_{\mathrm{t\bar{t}}}$ is studied. Five different PDF sets, available at NNLO, are employed and for each a series of different choices of $\alpha_S(m_{\mathrm{Z}})$ are considered. A simultaneous extraction of top-quark mass and strong coupling constant from the total $\mathrm{t\bar{t}}$ cross section alone is not possible since both parameters alter the predicted $\sigma_{\mathrm{t\bar{t}}}$ in such a way that any variation of one parameter can be compensated by a variation of the other. Values of $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_{\mathrm{Z}})$ are therefore determined at fixed values of $\alpha_S(m_{\mathrm{Z}})$ and $m_{\mathrm{t}}^{\mathrm{pole}}$, respectively. For the $m_{\mathrm{t}}^{\mathrm{pole}}$ extraction, $\alpha_S(m_{\mathrm{Z}})$ is constrained to the latest world average value with its corresponding uncertainty (0.1184 ± 0.0007) [26]. Furthermore, it is assumed that the m_{t} parameter of the Monte Carlo generator that is employed in the $\sigma_{\mathrm{t\bar{t}}}$ measurement is equal to $m_{\mathrm{t}}^{\mathrm{pole}}$ within ± 1.00 GeV [20]. For the α_S extraction, $m_{\mathrm{t}}^{\mathrm{pole}}$ is set to the Tevatron average of 173.18 ± 0.94 GeV [14]. To account for the possible difference between the pole mass and the Monte Carlo generator mass [20], an additional uncertainty, assumed to be 1.00 GeV, is added in quadrature to the experimental uncertainty, resulting in a total uncertainty on the top-quark mass constraint, $\delta m_{\mathrm{t}}^{\mathrm{pole}}$, of 1.4 GeV. Although the potential α_S dependence of the direct m_{t} measurements has not been explicitly evaluated, it is assumed to be covered by the quoted mass uncertainty.

2. Predicted cross section

The expected $\sigma_{\mathrm{t\bar{t}}}$ has been calculated to NNLO for all production channels, namely the all-fermionic scattering modes ($\mathrm{q\bar{q}}$, $\mathrm{qq'}$, $\mathrm{q\bar{q}'}$, $\mathrm{qq} \to \mathrm{t\bar{t}} + X$) [36,37], the reaction $\mathrm{qg} \to \mathrm{t\bar{t}} + X$ [38], and the dominant process $\mathrm{gg} \to \mathrm{t\bar{t}} + X$ [11]. In the present analysis, these calculations are used as implemented in the program Top++ 2.0 [39]. Soft-gluon resummation is performed at next-to-next-leading-log (NNLL) accuracy [40,41]. The scales μ_R and μ_F are set to $m_{\mathrm{t}}^{\mathrm{pole}}$. In order to evaluate the theoretical uncertainty of the fixed-order calculation, the missing contributions from higher orders are estimated by varying μ_R and μ_F up and down by a factor of 2 independently, while using the restriction $0.5 \leqslant \mu_F/\mu_R \leqslant 2$. These choices for the central scale and the variation procedure were suggested by the authors of the NNLO calculations and used for earlier $\sigma_{\mathrm{t\bar{t}}}$ predictions as well [42].

Five different NNLO PDF sets are employed: ABM11 [43], CT10 [44], HERAPDF1.5 [45], MSTW2008 [46,47], and NNPDF2.3 [48]. The corresponding uncertainties are calculated at the 68% confidence level for all PDF sets. This is done by recalculating the $\sigma_{\mathrm{t\bar{t}}}$ at NNLO + NNLL for each of the provided eigenvectors or replicas of the respective PDF set and then performing error propagation according to the prescription of that PDF group. In the specific case of the CT10 PDF set, the uncertainties are provided for the 90% confidence level only. For this Letter, following the recommendation of the CTEQ group, these uncertainties are adjusted using the general relation between confidence intervals based on Gaussian distributions [26], i.e., scaled down by a factor of $\sqrt{2}\,\mathrm{erf}^{-1}(0.90) = 1.64$, where erf denotes the error function.

The dependence of the predicted $\sigma_{\mathrm{t\bar{t}}}$ on the choice of $m_{\mathrm{t}}^{\mathrm{pole}}$ is studied by varying $m_{\mathrm{t}}^{\mathrm{pole}}$ in the range from 130 to 220 GeV in steps of 1 GeV and found to be well described by a third-order polynomial in $m_{\mathrm{t}}^{\mathrm{pole}}$ divided by $(m_{\mathrm{t}}^{\mathrm{pole}})^4$. The α_S dependence of $\sigma_{\mathrm{t\bar{t}}}$ is studied by varying the value of $\alpha_S(m_{\mathrm{Z}})$ over the entire valid range for a particular PDF set, as listed in Table 1. The relative change of $\sigma_{\mathrm{t\bar{t}}}$ as a function of $\alpha_S(m_{\mathrm{Z}})$ can be parametrized using a second-order polynomial in $\alpha_S(m_{\mathrm{Z}})$, where the three coefficients of that polynomial depend linearly on $m_{\mathrm{t}}^{\mathrm{pole}}$.

The resulting $\sigma_{\mathrm{t\bar{t}}}$ predictions are compared in Fig. 1, both as a function of $m_{\mathrm{t}}^{\mathrm{pole}}$ and of $\alpha_S(m_{\mathrm{Z}})$. For a given value of $\alpha_S(m_{\mathrm{Z}})$, the predictions based on NNPDF2.3 and CT10 are very similar. The cross sections obtained with MSTW2008 and HERAPDF1.5 are

Table 1
Default $\alpha_S(m_Z)$ values and $\alpha_S(m_Z)$ variation ranges of the NNLO PDF sets used in this analysis. Because the NNPDF2.3 PDF set does not have a default value of $\alpha_S(m_Z)$, preferring to provide the full uncertainties and systematic variations for various $\alpha_S(m_Z)$ points, the $\alpha_S(m_Z)$ value obtained by the NNPDF Collaboration with NNPDF2.1 [49] is used. The step size for the $\alpha_S(m_Z)$ scans is 0.0010 in all cases. The uncertainties on the default values are shown for illustration purposes only.

	Default $\alpha_S(m_Z)$	Uncertainty	Provided $\alpha_S(m_Z)$ scan	
			Range	# of points
ABM11	0.1134	±0.0011	0.1040–0.1200	17
CT10	0.1180	±0.0020	0.1100–0.1300	21
HERAPDF1.5	0.1176	±0.0020	0.1140–0.1220	9
MSTW2008	0.1171	±0.0014	0.1070–0.1270	21
NNPDF2.3	0.1174	±0.0007	0.1140–0.1240	11

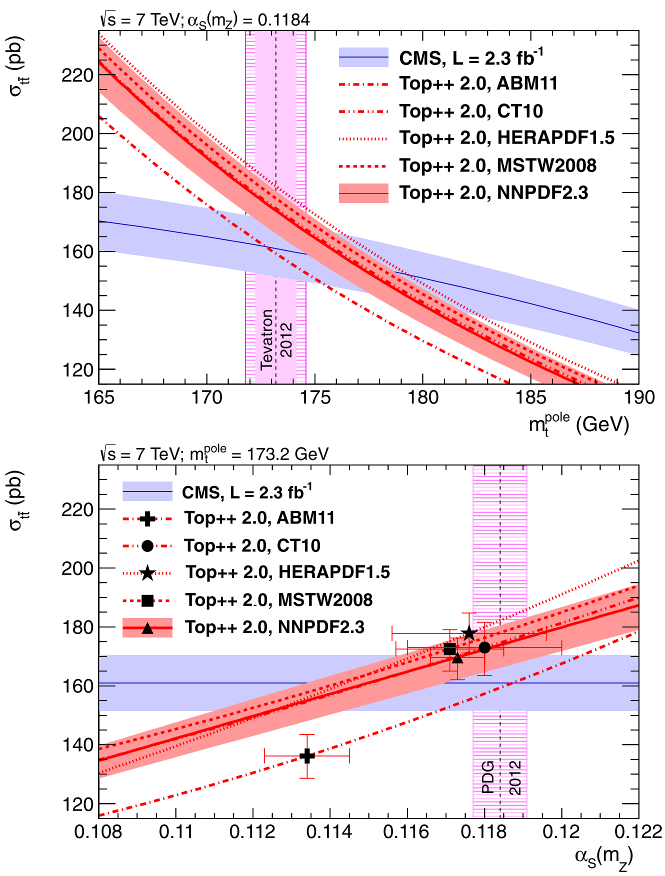

Fig. 1. Predicted $t\bar{t}$ cross section at NNLO + NNLL, as a function of the top-quark pole mass (top) and of the strong coupling constant (bottom), using five different NNLO PDF sets, compared to the cross section measured by CMS assuming $m_t = m_t^{pole}$. The uncertainties on the measured $\sigma_{t\bar{t}}$ as well as the renormalization and factorization scale and PDF uncertainties on the prediction with NNPDF2.3 are illustrated with filled bands. The uncertainties on the $\sigma_{t\bar{t}}$ predictions using the other PDF sets are indicated only in the bottom panel at the corresponding default $\alpha_S(m_Z)$ values. The m_t^{pole} and $\alpha_S(m_Z)$ regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, are shown as hatched areas. In the top panel, the inner (solid) area of the vertical band corresponds to the original uncertainty of the direct m_t average, while the outer (hatched) area additionally accounts for the possible difference between this mass and m_t^{pole}.

slightly higher while the predictions obtained with ABM11 are significantly lower due to a smaller gluon density in the relevant kinematic range [43]. In addition to the absolute normalization, differences in the slope of $\sigma_{t\bar{t}}$ as a function of $\alpha_S(m_Z)$ are observed between some of the PDF sets.

3. Measured cross section

In this Letter, the most precise single measurement for $\sigma_{t\bar{t}}$ [6] is used. It was derived at $\sqrt{s} = 7$ TeV by the CMS Collaboration from data collected in 2011 in the dileptonic decay channel and corresponding to an integrated luminosity of 2.3 fb^{-1}. Assuming $m_t = 172.5$ GeV and $\alpha_S(m_Z) = 0.1180$, the observed cross section is 161.9 ± 6.7 pb. Systematic effects on this measurement from the choice and uncertainties of the PDFs were studied and found to be negligible.

The measured $\sigma_{t\bar{t}}$ shows a dependence on the value of m_t that is used in the Monte Carlo simulations since the change in the event kinematics affects the expected selection efficiency and thus the acceptance corrections that are employed to infer $\sigma_{t\bar{t}}$ from the observed event yield. A parametrization for this dependence, which is illustrated in Fig. 1, was already given in Section 8 of Ref. [6]. At $m_t = 173.2$ GeV, for example, the observed cross section is 161.0 pb. The relative uncertainty of 4.1% on the measured $\sigma_{t\bar{t}}$ is independent of m_t to very good approximation.

Changes of the assumed value of $\alpha_S(m_Z)$ in the simulation used to derive the acceptance corrections can alter the measured $\sigma_{t\bar{t}}$ as well, which is discussed in this Letter for the first time. QCD radiation effects increase at higher $\alpha_S(m_Z)$, both at the matrix-element level and at the hadronization level. The $\alpha_S(m_Z)$-dependence of the acceptance corrections is studied using the NLO CTEQ6AB PDF sets [50], and the POWHEG Box 1.4 [51,52] NLO generator for $t\bar{t}$ production interfaced with PYTHIA 6.4.24 [53] for the parton showering. Additionally, the impact of $\alpha_S(m_Z)$ variations on the acceptance is studied with standalone PYTHIA as a plain leading-order generator with parton showering and cross-checked with MCFM 6.2 [54] as an NLO prediction without parton showering. In all cases, a relative change of the acceptance by less than 1% is observed when varying $\alpha_S(m_Z)$ by ± 0.0100 with respect to the CTEQ reference value of 0.1180. This is accounted for by applying an $\alpha_S(m_Z)$-dependent uncertainty to the measured $\sigma_{t\bar{t}}$. This additional uncertainty is also included in the uncertainty band shown in Fig. 1. Over the relevant $\alpha_S(m_Z)$ range, there is almost no increase in the total uncertainty of 4.1% on the measured $\sigma_{t\bar{t}}$.

In the m_t and $\alpha_S(m_Z)$ regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, the measured and the predicted cross section are compatible within their uncertainties for all considered PDF sets. When using ABM11 with its default $\alpha_S(m_Z)$, the discrepancy between measured and predicted cross section is larger than one standard deviation.

4. Probabilistic approach

In the following, the theory prediction for $\sigma_{t\bar{t}}$ is employed to construct a Bayesian prior to the cross section measurement, from which a joint posterior in $\sigma_{t\bar{t}}$, m_t^{pole} and $\alpha_S(m_Z)$ is derived. Finally, this posterior is marginalized by integration over $\sigma_{t\bar{t}}$ and a Bayesian confidence interval for m_t^{pole} or $\alpha_S(m_Z)$ is computed based on the external constraint for $\alpha_S(m_Z)$ or m_t^{pole}, respectively.

The probability function for the predicted cross section, $f_{th}(\sigma_{t\bar{t}})$, is obtained through an analytic convolution of two probability distributions, one accounting for the PDF uncertainty and the other for scale uncertainties. A Gaussian distribution of width δ_{PDF} is used to describe the PDF uncertainty. Given that no particular probability distribution is known that should be adequate for the confidence interval obtained from the variation of μ_R and μ_F [42], the corresponding uncertainty on the $\sigma_{t\bar{t}}$ prediction is approximated using a flat prior, i.e., a rectangular function that provides equal probability over the whole range covered by the scale

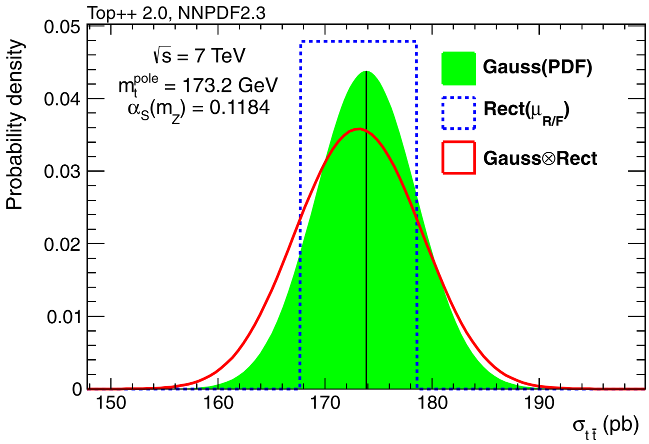

Fig. 2. Probability distributions for the predicted $t\bar{t}$ cross section at NNLO + NNLL with $m_t^{pole} = 173.2$ GeV, $\alpha_S(m_Z) = 0.1184$ and the NNLO parton distributions from NNPDF2.3. The resulting probability, $f_{th}(\sigma_{t\bar{t}})$, represented by a solid line, is obtained by convolving a Gaussian distribution (filled area) that accounts for the PDF uncertainty with a rectangular function (dashed line) that covers the scale variation uncertainty.

variation and vanishes elsewhere. The resulting probability function is given by:

$$f_{th}(\sigma_{t\bar{t}}) = \frac{1}{2(\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}^{(l)})}\left(\mathrm{erf}\left[\frac{\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}}{\sqrt{2}\delta_{PDF}}\right] - \mathrm{erf}\left[\frac{\sigma_{t\bar{t}}^{(l)} - \sigma_{t\bar{t}}}{\sqrt{2}\delta_{PDF}}\right]\right).$$

Here, $\sigma_{t\bar{t}}^{(l)}$ and $\sigma_{t\bar{t}}^{(h)}$ denote the lowest and the highest cross section values, respectively, that are obtained when varying μ_R and μ_F as described in Section 2. An example for the resulting probability distributions is shown in Fig. 2.

The probability distribution $f_{th}(\sigma_{t\bar{t}})$ is multiplied by another Gaussian probability, $f_{exp}(\sigma_{t\bar{t}})$, which represents the measured cross section and its uncertainty, to obtain the most probable m_t^{pole} or $\alpha_S(m_Z)$ value for a given $\alpha_S(m_Z)$ or m_t^{pole}, respectively, from the maximum of the marginalized posterior:

$$P(x) = \int f_{exp}(\sigma_{t\bar{t}}|x) f_{th}(\sigma_{t\bar{t}}|x)\, d\sigma_{t\bar{t}}, \quad x = m_t^{pole},\ \alpha_S(m_Z).$$

Examples of $P(m_t^{pole})$ and $P(\alpha_S)$ are shown in Fig. 3. Confidence intervals are determined from the 68% area around the maximum of the posterior and requiring equal function values at the left and right edges.

The approximate contributions of the uncertainties on the measured and the predicted cross sections to the width of this Bayesian confidence interval can be estimated by repeatedly rescaling the size of the corresponding uncertainty component. The widths of the obtained confidence intervals are then used to extrapolate to the case in which a given component vanishes.

To assess the impact of the uncertainties on the $\alpha_S(m_Z)$ and m_t^{pole} values that are used as constraints in the present analysis, $P(m_t^{pole})$ is re-evaluated at $\alpha_S(m_Z) = 0.1177$ and 0.1191, reflecting the ± 0.0007 uncertainty on the $\alpha_S(m_Z)$ world average, and $P(\alpha_S)$ is re-evaluated at $m_t^{pole} = 171.8$ and 174.6 GeV, reflecting the $\delta m_t^{pole} = 1.4$ GeV as explained in Section 1. The resulting shifts in the most likely values of m_t^{pole} and $\alpha_S(m_Z)$ are added in quadrature to those obtained from the 68% areas of the posteriors calculated with the central values of the constraints.

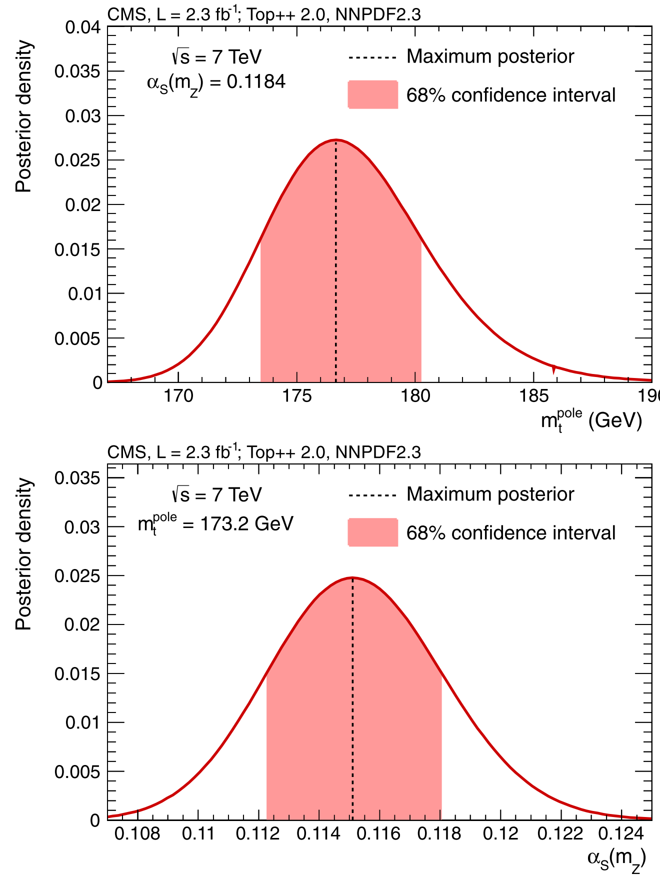

Fig. 3. Marginal posteriors $P(m_t^{pole})$ (top) and $P(\alpha_S)$ (bottom) based on the cross section prediction at NNLO + NNLL with the NNLO parton distributions from NNPDF2.3. The posteriors are constructed as described in the text. Here, $P(m_t^{pole})$ is shown for $\alpha_S(m_Z) = 0.1184$ and $P(\alpha_S)$ for $m_t^{pole} = 173.2$ GeV.

5. Results and conclusions

Values of the top-quark pole mass determined using the $t\bar{t}$ cross section measured by CMS together with the cross section prediction from NNLO + NNLL QCD and five different NNLO PDF sets are listed in Table 2. These values are extracted under the assumption that the m_t parameter in the Monte Carlo generator that was employed to obtain the mass-dependent acceptance correction of the measured cross section, shown in Fig. 1, is equal to the pole mass. A difference of 1.0 GeV between the two mass definitions [20] would result in changes of 0.3–0.6 GeV in the extracted pole masses, which is included as a systematic uncertainty. As illustrated in Fig. 4, the results based on NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are higher than the latest average of direct m_t measurements but generally compatible within the uncertainties. They are also consistent with the indirect determination of the top-quark pole mass obtained in the electroweak fits [55,56] when employing the mass of the new boson discovered at the LHC [57,58] under the assumption that this is the SM Higgs boson. The central m_t^{pole} value obtained with the ABM11 PDF set, which has a significantly smaller gluon density than the other PDF sets, is also compatible with the average from direct m_t measurements. Note, however, that all these results in Table 2 are obtained employing the $\alpha_S(m_Z)$ world average of 0.1184 ± 0.0007, while ABM11 with its default $\alpha_S(m_Z)$ of 0.1134 ± 0.0011 would yield an m_t^{pole} value of $166.3^{+3.3}_{-3.1}$ GeV.

Table 2
Results obtained for m_t^{pole} by comparing the measured $t\bar{t}$ cross section to the NNLO + NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ($\sigma_{t\bar{t}}^{meas}$), the PDF and scale ($\mu_{R,F}$) uncertainties on the predicted cross section, the uncertainties of the $\alpha_S(m_Z)$ world average and of the LHC beam energy (E_{LHC}), and the ambiguity in translating the dependence of the measured cross section on the top-quark mass value used in the Monte Carlo generator (m_t^{MC}) into the pole-mass scheme.

	m_t^{pole} (GeV)	Uncertainty on m_t^{pole} (GeV)						
		Total	$\sigma_{t\bar{t}}^{meas}$	PDF	$\mu_{R,F}$	α_S	E_{LHC}	m_t^{MC}
ABM11	172.7	$^{+3.9}_{-3.5}$	$^{+2.8}_{-2.5}$	$^{+2.2}_{-2.0}$	$^{+0.7}_{-0.7}$	$^{+1.0}_{-1.0}$	$^{+0.8}_{-0.8}$	$^{+0.4}_{-0.3}$
CT10	177.0	$^{+4.3}_{-3.8}$	$^{+3.2}_{-2.8}$	$^{+2.4}_{-2.0}$	$^{+0.9}_{-0.9}$	$^{+0.8}_{-0.8}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.4}$
HERAPDF1.5	179.5	$^{+4.3}_{-3.8}$	$^{+3.5}_{-3.0}$	$^{+1.7}_{-1.5}$	$^{+0.9}_{-0.8}$	$^{+1.2}_{-1.1}$	$^{+1.0}_{-1.0}$	$^{+0.6}_{-0.5}$
MSTW2008	177.9	$^{+4.1}_{-3.6}$	$^{+3.4}_{-2.9}$	$^{+1.6}_{-1.4}$	$^{+0.9}_{-0.9}$	$^{+0.9}_{-0.9}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.5}$
NNPDF2.3	176.7	$^{+3.8}_{-3.4}$	$^{+3.1}_{-2.8}$	$^{+1.5}_{-1.3}$	$^{+0.9}_{-0.9}$	$^{+0.7}_{-0.7}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.4}$

Table 3
Results obtained for $\alpha_S(m_Z)$ by comparing the measured $t\bar{t}$ cross section to the NNLO + NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ($\sigma_{t\bar{t}}^{meas}$), the PDF and scale ($\mu_{R,F}$) uncertainties on the predicted cross section, the uncertainty assigned to the knowledge of m_t^{pole}, and the uncertainty of the LHC beam energy (E_{LHC}).

	$\alpha_S(m_Z)$	Uncertainty on $\alpha_S(m_Z)$					
		Total	$\sigma_{t\bar{t}}^{meas}$	PDF	$\mu_{R,F}$	m_t^{pole}	E_{LHC}
ABM11	0.1187	$^{+0.0027}_{-0.0027}$	$^{+0.0018}_{-0.0019}$	$^{+0.0015}_{-0.0014}$	$^{+0.0006}_{-0.0005}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
CT10	0.1151	$^{+0.0034}_{-0.0034}$	$^{+0.0024}_{-0.0025}$	$^{+0.0018}_{-0.0016}$	$^{+0.0008}_{-0.0007}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0007}$
HERAPDF1.5	0.1143	$^{+0.0024}_{-0.0024}$	$^{+0.0018}_{-0.0019}$	$^{+0.0010}_{-0.0009}$	$^{+0.0005}_{-0.0004}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
MSTW2008	0.1144	$^{+0.0031}_{-0.0032}$	$^{+0.0024}_{-0.0025}$	$^{+0.0012}_{-0.0011}$	$^{+0.0008}_{-0.0007}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0008}$
NNPDF2.3	0.1151	$^{+0.0033}_{-0.0032}$	$^{+0.0025}_{-0.0025}$	$^{+0.0013}_{-0.0011}$	$^{+0.0009}_{-0.0008}$	$^{+0.0013}_{-0.0013}$	$^{+0.0008}_{-0.0008}$

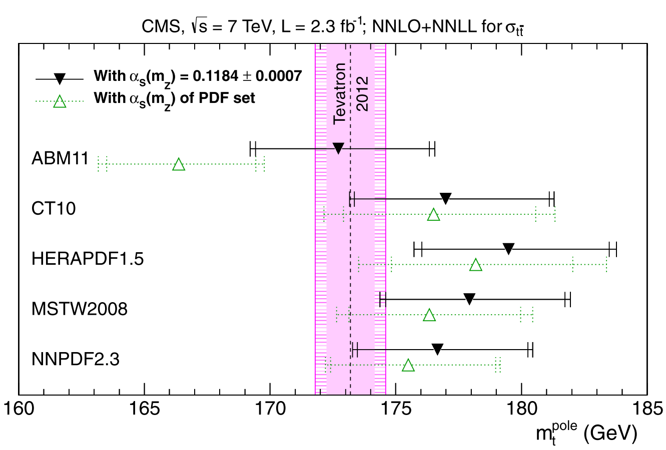

Fig. 4. Results obtained for m_t^{pole} from the measured $t\bar{t}$ cross section together with the prediction at NNLO + NNLL using different NNLO PDF sets. The filled symbols represent the results obtained when using the $\alpha_S(m_Z)$ world average, while the open symbols indicate the results obtained with the default $\alpha_S(m_Z)$ value of the respective PDF set. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on the $\alpha_S(m_Z)$ value used for a specific prediction. For comparison, the latest average of direct m_t measurements is shown as vertical band, where the inner (solid) area corresponds to the original uncertainty of the direct m_t average, while the outer (hatched) area additionally accounts for the possible difference between this mass and m_t^{pole}.

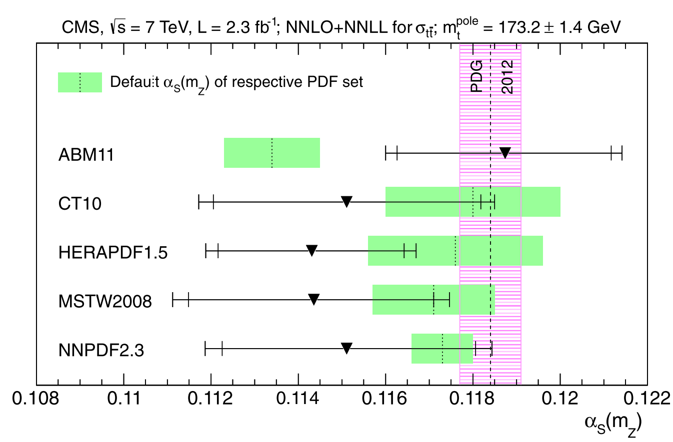

Fig. 5. Results obtained for $\alpha_S(m_Z)$ from the measured $t\bar{t}$ cross section together with the prediction at NNLO + NNLL using different NNLO PDF sets. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on m_t^{pole}. For comparison, the latest $\alpha_S(m_Z)$ world average with its uncertainty is shown as a hatched band. For each PDF set, the default $\alpha_S(m_Z)$ value and its uncertainty are indicated using a dotted line and a shaded band.

The $\alpha_S(m_Z)$ values obtained when fixing the value of m_t^{pole} to 173.2 ± 1.4 GeV, i.e., inverting the logic of the extraction, are listed in Table 3. As illustrated in Fig. 5, the results obtained using NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are lower than the $\alpha_S(m_Z)$ world average but in most cases still compatible with it within the uncertainties. While the $\alpha_S(m_Z)$ value obtained with ABM11 is compatible with the world average, it is significantly different from the default $\alpha_S(m_Z)$ of this PDF set.

Modeling the uncertainty related to the choice and variation of the renormalization and factorization scales with a Gaussian instead of the flat prior results in only minor changes of the m_t^{pole} and $\alpha_S(m_Z)$ values and uncertainties. With the precise NNLO + NNLL calculation, these scale uncertainties are found to be of the size of 0.7–0.9 GeV on m_t^{pole} and 0.0004–0.0009 on $\alpha_S(m_Z)$, i.e., of the order of 0.3–0.8%.

The energy of the LHC beams is known to an accuracy of 0.65% [59] and thus the center-of-mass energy of 7 TeV with an uncertainty of ±46 GeV. Based on the expected dependence of $\sigma_{t\bar{t}}$ on $\sqrt{s}$, this can be translated into an additional uncertainty of ±1.8% on the comparison of the measured to the predicted $t\bar{t}$ cross section, which yields an additional uncertainty of $\pm(0.5–0.7)$% on the obtained m_t^{pole} and $\alpha_S(m_Z)$ values.

For the main results of this Letter, the m_t^{pole} and $\alpha_S(m_Z)$ values determined with the parton densities of NNPDF2.3 are used. The primary motivation is that parton distributions derived using the NNPDF methodology can be explicitly shown to be parametrization independent, in the sense that results are unchanged even when the number of input parameters is substantially increased [60].

In summary, a top-quark pole mass of $176.7^{+3.8}_{-3.4}$ GeV is obtained by comparing the measured cross section for inclusive $t\bar{t}$ production in proton–proton collisions at $\sqrt{s} = 7$ TeV to QCD calculations at NNLO + NNLL. Due to the small uncertainty on the measured cross section and the state-of-the-art NNLO calculations, the precision of this result is higher compared to earlier determinations of m_t^{pole} following the same approach. This extraction provides an important test of the mass scheme applied in Monte Carlo simulations and gives complementary information, with different sensitivity to theoretical and experimental uncertainties, than direct measurements of m_t. Alternatively, $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$ is obtained from the $t\bar{t}$ cross section when constraining m_t^{pole} to 173.2 ± 1.4 GeV. This is the first determination of the strong coupling constant from top-quark production and the first $\alpha_S(m_Z)$ result at full NNLO QCD obtained at a hadron collider.

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References

[1] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 3 (2008) S08004, http://dx.doi.org/10.1088/1748-0221/3/08/S08004.
[2] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section and the top quark mass in the dilepton channel in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 1107 (2011) 049, arXiv:1105.5661.
[3] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV using the kinematic properties of events with leptons and jets, Eur. Phys. J. C 71 (2011) 1721, http://dx.doi.org/10.1140/epjc/s10052-011-1721-3, arXiv:1106.0902.
[4] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in *pp* collisions at 7 TeV in lepton + jets events using *b*-quark jet identification, Phys. Rev. D 84 (2011) 092004, http://dx.doi.org/10.1103/PhysRevD.84.092004, arXiv:1108.3773.
[5] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV in dilepton final states containing a τ, Phys. Rev. D 85 (2012) 112007, http://dx.doi.org/10.1103/PhysRevD.85.112007, arXiv:1203.6810.
[6] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in the dilepton channel in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 1211 (2012) 067, http://dx.doi.org/10.1007/JHEP11(2012)067, arXiv:1208.2671.
[7] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV with lepton + jets final states, Phys. Lett. B 720 (2013) 83, http://dx.doi.org/10.1016/j.physletb.2013.02.021, arXiv:1212.6682.
[8] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in the τ + jets channel in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 73 (2013) 2386, http://dx.doi.org/10.1140/epjc/s10052-013-2386-x, arXiv:1301.5755.
[9] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in the all-jet final state in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 1305 (2013) 065, http://dx.doi.org/10.1007/JHEP05(2013)065, arXiv:1302.0508.
[10] CMS Collaboration, Measurement of differential top-quark pair production cross sections in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 73 (2013) 2339, http://dx.doi.org/10.1140/epjc/s10052-013-2339-4, arXiv:1211.2220.
[11] M. Czakon, P. Fiedler, A. Mitov, The total top quark pair production cross-section at hadron colliders through $\mathcal{O}(\alpha_S^4)$, Phys. Rev. Lett. 110 (2013) 252004, http://dx.doi.org/10.1103/PhysRevLett.110.252004, arXiv:1303.6254.
[12] G. Degrassi, S. Di Vita, J. Elias-Miro, J.R. Espinosa, G.F. Giudice, G. Isidori, A. Strumia, Higgs mass and vacuum stability in the Standard Model at NNLO, J. High Energy Phys. 1208 (2012) 098, http://dx.doi.org/10.1007/JHEP08(2012)098, arXiv:1205.6497.
[13] S. Alekhin, A. Djouadi, S. Moch, The top quark and Higgs boson masses and the stability of the electroweak vacuum, Phys. Lett. B 716 (2012) 214, http://dx.doi.org/10.1016/j.physletb.2012.08.024, arXiv:1207.0980.
[14] CDF Collaboration, D0 Collaboration, Combination of the top-quark mass measurements from the Tevatron collider, Phys. Rev. D 86 (2012) 092003, http://dx.doi.org/10.1103/PhysRevD.86.092003, arXiv:1207.1069, an update can be found in arXiv:1305.3929.
[15] CMS Collaboration, Measurement of the top-quark mass in $t\bar{t}$ events with lepton + jets final states in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 1212 (2012) 105, http://dx.doi.org/10.1007/JHEP12(2012)105, arXiv:1209.2319.
[16] CMS Collaboration, Measurement of the top-quark mass in $t\bar{t}$ events with dilepton final states in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 72 (2012) 2202, http://dx.doi.org/10.1140/epjc/s10052-012-2202-z, arXiv:1209.2393.
[17] CMS Collaboration, Measurement of masses in the $t\bar{t}$ system by kinematic endpoints in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 73 (2013) 2494, http://dx.doi.org/10.1140/epjc/s10052-013-2494-7, arXiv:1304.5783.
[18] A.H. Hoang, I.W. Stewart, Top mass measurements from jets and the Tevatron top-quark mass, Nucl. Phys. B, Proc. Suppl. 185 (2008) 220, http://dx.doi.org/10.1016/j.nuclphysbps.2008.10.028, arXiv:0808.0222.
[19] V. Ahrens, A. Ferroglia, M. Neubert, B.D. Pecjak, L.L. Yang, Precision predictions for the $t\bar{t}$ production cross section at hadron colliders, Phys. Lett. B 703 (2011) 135, http://dx.doi.org/10.1016/j.physletb.2011.07.058, arXiv:1105.5824.
[20] A. Buckley, J. Butterworth, S. Gieseke, D. Grellscheid, S. Höche, H. Hoeth, F. Krauss, L. Lönnblad, E. Nurse, P. Richardson, S. Schumann, M.H. Seymour, T. Sjöstrand, P. Skands, B. Webber, General-purpose event generators for LHC physics, Phys. Rep. 504 (2011) 145, http://dx.doi.org/10.1016/j.physrep.2011.03.005, arXiv:1101.2599.
[21] U. Langenfeld, S. Moch, P. Uwer, Measuring the running top-quark mass, Phys. Rev. D 80 (2009) 054009, http://dx.doi.org/10.1103/PhysRevD.80.054009, arXiv:0906.5273.
[22] V.M. Abazov, et al., D0 Collaboration, Determination of the pole and $\overline{\text{MS}}$ masses of the top quark from the $t\bar{t}$ cross section, Phys. Lett. B 703 (2011) 422, http://dx.doi.org/10.1016/j.physletb.2011.08.015, arXiv:1104.2887.
[23] M. Beneke, P. Falgari, S. Klein, C. Schwinn, Hadronic top-quark pair production with NNLL threshold resummation, Nucl. Phys. B 855 (2012) 695, http://dx.doi.org/10.1016/j.nuclphysb.2011.10.021, arXiv:1109.1536.
[24] M. Beneke, P. Falgari, S. Klein, J. Piclum, C. Schwinn, M. Ubiali, F. Yan, Inclusive top-pair production phenomenology with TOPIXS, J. High Energy Phys. 1207 (2012) 194, http://dx.doi.org/10.1007/JHEP07(2012)194, arXiv:1206.2454.
[25] F. Jegerlehner, M.Y. Kalmykov, B.A. Kniehl, On the difference between the pole and the $\overline{\text{MS}}$ masses of the top quark at the electroweak scale, Phys. Lett. B 722 (2013) 123, http://dx.doi.org/10.1016/j.physletb.2013.04.012, arXiv:1212.4319.
[26] Particle Data Group, J. Berringer, et al., Review of particle physics, Phys. Rev. D 86 (2012) 010001, http://dx.doi.org/10.1103/PhysRevD.86.010001.
[27] G. Dissertori, A. Gehrmann-De Ridder, T. Gehrmann, E.W.N. Glover, G. Heinrich, G. Luisoni, H. Stenzel, Determination of the strong coupling constant using matched NNLO + NLLA predictions for hadronic event shapes in e^+e^- annihilations, J. High Energy Phys. 0908 (2009) 036, http://dx.doi.org/10.1088/1126-6708/2009/08/036, arXiv:0906.3436.
[28] G. Abbiendi, et al., OPAL Collaboration, Determination of α_S using OPAL hadronic event shapes at $\sqrt{s} = 91–209$ GeV and resummed NNLO calculations, Eur. Phys. J. C 71 (2011) 1733, http://dx.doi.org/10.1140/epjc/s10052-011-1733-z, arXiv:1101.1470.

[29] G. Dissertori, A. Gehrmann-DeRidder, T. Gehrmann, E.W.N. Glover, G. Heinrich, H. Stenzel, Precise determination of the strong coupling constant at NNLO in QCD from the three-jet rate in electron–positron annihilation at LEP, Phys. Rev. Lett. 104 (2010) 072002, http://dx.doi.org/10.1103/PhysRevLett.104.072002, arXiv:0910.4283.

[30] R. Abbate, M. Fickinger, A.H. Hoang, V. Mateu, I.W. Stewart, Thrust at N^3LL with power corrections and a precision global fit for $\alpha_S(m_Z)$, Phys. Rev. D 83 (2011) 074021, http://dx.doi.org/10.1103/PhysRevD.83.074021, arXiv:1006.3080.

[31] V.M. Abazov, et al., D0 Collaboration, Measurement of angular correlations of jets at $\sqrt{s} = 1.96$ TeV and determination of the strong coupling at high momentum transfers, Phys. Lett. B 718 (2012) 56, http://dx.doi.org/10.1016/j.physletb.2012.10.003, arXiv:1207.4957.

[32] B. Malaescu, P. Starovoitov, Evaluation of the strong coupling constant α_s using the ATLAS inclusive jet cross-section data, Eur. Phys. J. C 72 (2012) 2041, http://dx.doi.org/10.1140/epjc/s10052-012-2041-y, arXiv:1203.5416.

[33] CMS Collaboration, Measurement of the ratio of the inclusive 3-jet cross section to the inclusive 2-jet cross section in pp collisions at $\sqrt{s} = 7$ TeV and first determination of the strong coupling constant in the TeV range, Eur. Phys. J. C (2013), http://dx.doi.org/10.1140/epjc/s10052-013-2604-6, arXiv:1304.7498.

[34] V.M. Abazov, et al., D0 Collaboration, Determination of the strong coupling constant from the inclusive jet cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, Phys. Rev. D 80 (2009) 111107, http://dx.doi.org/10.1103/PhysRevD.80.111107, arXiv:0911.2710.

[35] M. Czakon, M.L. Mangano, A. Mitov, J. Rojo, Constraints on the gluon PDF from top quark pair production at hadron colliders, arXiv:1303.7215, 2013.

[36] P. Bärnreuther, M. Czakon, A. Mitov, Percent-level-precision physics at the tevatron: next-to-next-to-leading order QCD corrections to $q\bar{q} \to t\bar{t} + X$, Phys. Rev. Lett. 109 (2012) 132001, http://dx.doi.org/10.1103/PhysRevLett.109.132001, arXiv:1204.5201.

[37] M. Czakon, A. Mitov, NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels, J. High Energy Phys. 1212 (2012) 054, http://dx.doi.org/10.1007/JHEP12(2012)054, arXiv:1207.0236.

[38] M. Czakon, A. Mitov, NNLO corrections to top pair production at hadron colliders: the quark–gluon reaction, J. High Energy Phys. 1301 (2013) 080, http://dx.doi.org/10.1007/JHEP01(2013)080, arXiv:1210.6832.

[39] M. Czakon, A. Mitov, Top++: a program for the calculation of the top-pair cross-section at hadron colliders, arXiv:1112.5675, 2011.

[40] M. Beneke, P. Falgari, C. Schwinn, Soft radiation in heavy-particle pair production: All-order colour structure and two-loop anomalous dimension, Nucl. Phys. B 828 (2010) 69, http://dx.doi.org/10.1016/j.nuclphysb.2009.11.004, arXiv:0907.1443.

[41] M. Czakon, A. Mitov, G.F. Sterman, Threshold resummation for top-pair hadroproduction to next-to-next-to-leading log, Phys. Rev. D 80 (2009) 074017, http://dx.doi.org/10.1103/PhysRevD.80.074017, arXiv:0907.1790.

[42] M. Cacciari, S. Frixione, M.L. Mangano, P. Nason, G. Ridolfi, Updated predictions for the total production cross sections of top and of heavier quark pairs at the Tevatron and at the LHC, J. High Energy Phys. 0809 (2008) 127, http://dx.doi.org/10.1088/1126-6708/2008/09/127, arXiv:0804.2800.

[43] S. Alekhin, J. Blümlein, S. Moch, Parton distribution functions and benchmark cross sections at next-to-next-to-leading order, Phys. Rev. D 86 (2012) 054009, http://dx.doi.org/10.1103/PhysRevD.86.054009, arXiv:1202.2281.

[44] J. Gao, M. Guzzi, J. Huston, H.-L. Lai, Z. Li, P. Nadolsk, J. Pumplin, D. Stump, C.-P. Yuan, The CT10 NNLO Global Analysis of QCD, arXiv:1302.6246, 2013.

[45] H1 Collaboration, ZEUS Collaboration, HERA combined results – proton structure: HERAPDF1.5 NNLO, https://www.desy.de/h1zeus/combined_results/index.php?do=proton_structure, h1prelim-11-042, ZEUS-prel-11-002.

[46] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Parton distributions for the LHC, Eur. Phys. J. C 63 (2009) 189, http://dx.doi.org/10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002.

[47] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Uncertainties on α_S in global PDF analyses and implications for predicted hadronic cross sections, Eur. Phys. J. C 64 (2009) 653, http://dx.doi.org/10.1140/epjc/s10052-009-1164-2, arXiv:0905.3531.

[48] R.D. Ball, V. Bertone, S. Carrazza, C.S. Deans, L.D. Debbio, S. Forte, A. Guffanti, N.P. Hartland, J.I. Latorre, J. Rojo, M. Ubiali, Parton distributions with LHC data, Nucl. Phys. B 867 (2013) 244, http://dx.doi.org/10.1016/j.nuclphysb.2012.10.003, arXiv:1207.1303.

[49] R.D. Ball, V. Bertone, L. Del Debbio, S. Forte, A. Guffanti, J.I. Latorre, S. Lionetti, J. Rojo, M. Ubiali, Precision NNLO determination of $\alpha_s(M_Z)$ using an unbiased global parton set, Phys. Lett. B 707 (2012) 66, http://dx.doi.org/10.1016/j.physletb.2011.11.053, arXiv:1110.2483.

[50] J. Pumplin, A. Belyaev, J. Huston, D. Stump, W.-K. Tung, Parton distributions and the strong coupling: CTEQ6AB PDFs, J. High Energy Phys. 0602 (2006) 032, http://dx.doi.org/10.1088/1126-6708/2006/02/032, arXiv:hep-ph/0512167.

[51] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, J. High Energy Phys. 1006 (2010) 043, http://dx.doi.org/10.1007/JHEP06(2010)043, arXiv:1002.2581.

[52] S. Frixione, P. Nason, G. Ridolfi, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, J. High Energy Phys. 0709 (2007) 126, http://dx.doi.org/10.1088/1126-6708/2007/09/126, arXiv:0707.3088.

[53] T. Sjöstrand, S. Mrenna, P.Z. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 0605 (2006) 026, http://dx.doi.org/10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[54] J.M. Campbell, R.K. Ellis, Top-quark processes at NLO in production and decay, arXiv:1204.1513, 2012.

[55] O. Eberhardt, G. Herbert, H. Lacker, A. Lenz, A. Menzel, U. Nierste, M. Wiebusch, Impact of a Higgs boson at a mass of 126 GeV on the standard model with three and four fermion generations, Phys. Rev. Lett. 109 (2012) 241802, http://dx.doi.org/10.1103/PhysRevLett.109.241802, arXiv:1209.1101.

[56] M. Baak, M. Goebel, J. Haller, A. Hoecker, D. Kennedy, R. Kogler, K. Mönig, M. Schott, J. Stelzer, The electroweak fit of the standard model after the discovery of a new boson at the LHC, Eur. Phys. J. C 72 (2012) 2205, http://dx.doi.org/10.1140/epjc/s10052-012-2205-9, arXiv:1209.2716.

[57] ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B 716 (2012) 1, http://dx.doi.org/10.1016/j.physletb.2012.08.020, arXiv:1207.7214.

[58] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Phys. Lett. B 716 (2012) 30, http://dx.doi.org/10.1016/j.physletb.2012.08.021, arXiv:1207.7235.

[59] J. Wenninger, Energy calibration of the LHC beams at 4 TeV, Accelerators & Technology Sector Reports, CERN-ATS-2013-040, CERN, 2013, http://cdsweb.cern.ch/record/1546734.

[60] R.D. Ball, L.D. Debbio, S. Forte, A. Guffanti, J.I. Latorre, A. Piccione, J. Rojo, M. Ubialia, A determination of parton distributions with faithful uncertainty estimation, Nucl. Phys. B 809 (2009) 1, http://dx.doi.org/10.1016/j.nuclphysb.2008.09.037, arXiv:0808.1231.

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